Guidelines for Utilizing *NC Statewide Crash Rates*

Glossary

Continuous Left Turn Lane: A roadway with a lane in the median area that is marked to provide a deceleration and storage area, out of the through-traffic stream, for vehicles traveling in either direction to use in making left turns.

Crash Rate: The number of crashes per unit of exposure. Typically crashes per million entering vehicles at intersections or crashes per million vehicle-miles on sections of highways.

Critical Crash Rate: A statistical derived number that can be used as a tool to identify or screen for high accident locations. Locations with a crash rate higher than the critical rate may have a potential highway safety deficiency and may deem additional analysis.

Divided: Roadway has a median that is designed to physically separate the two directions of travel. This includes mountable pavement, curb, grass or positive barrier medians.

Full Control Access: No at-grade street intersections or driveways are permitted on roads with full access control. Access to the highway is provided through interchanges with selected public roads.

Interstate: Routes that are classified on the Interstate highway system within the state of North Carolina (For example: I-40, I-277). This includes urban loop facilities but does not include interstate "business" routes. The "business" routes are included in the "United States" route crash data.

Night Crash (Rate): A crash that occurred when the ambient light condition was described as "Darkness".

No Control Access: Adjacent property owners are permitted one or more direct driveway connections to the street or highway.

Nonfatal Injury Crash (Rate): A crash that results in injuries, with no fatal injuries, to one or more persons.

Non-System: Routes that are not owned and maintained by NCDOT. (For example: a local city street, a national forest road, Indian reservation road)

North Carolina: Routes that are classified as a North Carolina Route within the state of North Carolina. (For example: NC 7, NC 273, NC 24 Business)

Number of Lanes: The total number of lanes for through traffic in both directions of travel. Does not include climbing lanes, passing lanes, turning lanes, and speed change lanes (ramp, weave lanes, etc.).

Partial Control Access: Adjacent property owners are allowed limited public crossroad intersections (at grade) and some carefully predetermined driveways.

Primary: All Routes that are classified as an Interstate Route, United States Route or North Carolina Route within the state of North Carolina. (For example: I 26, US 74 Alternate, NC 68)

Rural: Segments of highway outside the corporate limits of a city or town (for purposes of crash rates only).

Secondary Road: Routes that are classified as a State Secondary Route within the state of North Carolina. (For example: SR 1010, SR 2000)

Undivided: Roadway does not have a median between the two directions of travel.

United States: Routes that are classified as a United States Route or *Interstate Business Route* within the state of North Carolina. (For example: US 1, US 321, US 501 Business, I-95 Business)

Urban: Segments of highway inside the corporate limits of a city or town (for purposes of crash rates only).

Wet Crash (Rate): A crash that occurred when the roadway surface condition was described as "Wet" or "Water (standing, moving)".

Crash Rate Defined

Crash rate is defined as:

$$Crash\ Rate = \frac{Crash\ Count}{Exposure}$$

Exposure is typically derived from the annual average daily traffic (AADT). To calculate the exposure, you multiply the AADT by 365, the number of years in the study and the length of the roadway segment. To illustrate, if 145 crashes occurred on a 0.92 mile roadway section with a 24,000 weighted AADT during a three-year period, the crash rate is 145/(24000x365x3x0.92) = 5.99 *crashes/vehicle million-miles traveled* (or 599.18 *crashes per 100mvmt)*.

Selecting a Comparison Crash Rate (An Example)

To illustrate how to use the ***NC Statewide Rates***, we will find a comparison rate for an example roadway segment. Examine the map below of a section of US 301/NC 96 (Brightleaf Blvd.) in the town of Smithfield in Johnston County. The example section used is from SR 1921 (Hospital Road) to SR 1923 (Booker Dairy Road). US 301 is classified as a "United States" route; therefore, the rates on Page 3 of the ***2000-2002 NC Statewide Rates*** should be used *(See Exhibit 2)*. Also, this example section is within the city limits of Smithfield; therefore, the "urban" rate can be used. The cross section at this location is a four-lane roadway with a continuous left-turn lane similar to the roadway shown in Exhibit 7. Therefore, an appropriate comparison rate for the Total Crash Rate of this US 301 section is *374.08 crashes per 100 mvmt.* The average crash rate for all Urban United States Routes (346.74 *crashes per 100 mvmt*) could also be used as an alternative.

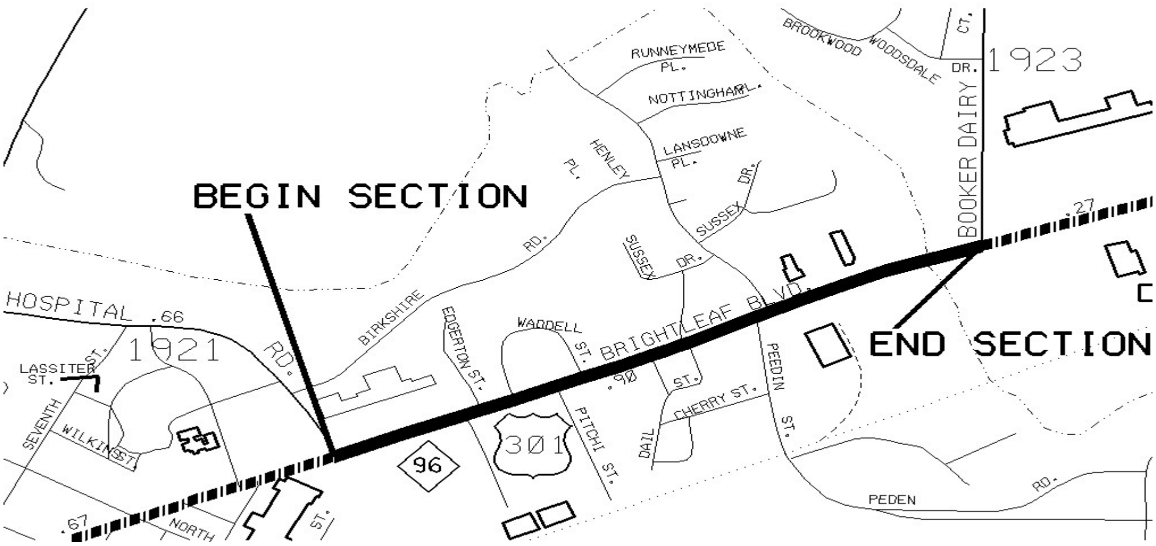

Exhibit 1 – Map of Example Section

URBAN UNITED STATES ROUTES						
ROAD TYPE	SYSTEM MILES	**TOTAL**	FATAL	NON-FATAL INJURY	NIGHT	WET
2 LANES UNDIVIDED	494	321.84	0.98	117.08	62.92	53.87
2 LANES CONT. LEFT TURN LANE	9	219.28	0.86	68.79	36.12	36.98
3 LANES UNDIVIDED	5	336.28	1.71	124.61	69.99	47.80
4 OR MORE LANES UNDIVIDED	119	631.41	1.49	235.78	120.71	109.43
4+ LANES CONT. LEFT TURN LANE	249	**374.08**	**1.19**	**138.79**	**75.20**	**69.30**
4 OR MORE LANES DIVIDED WITH:						
NO CONTROL ACCESS	192	432.42	1.23	145.91	91.93	72.71
PARTIAL CONTROL ACCESS	112	245.66	0.76	85.97	51.56	44.10
FULL CONTROL ACCESS	98	155.81	0.89	51.24	36.08	30.96
TOTAL	1,278	**346.74**	1.08	123.47	70.88	61.07

Exhibit 2 – 2000-2002 Crash Rates for Urban United States Routes *(from Page 3)*

Statewide, Division or County Crash Rates

The ***NC* S*tatewide Rates*** are typically used to examine groups of locations that are spread throughout the state of North Carolina. The division wide and countywide crash rates can be used to examine safety programs or groups of locations that are located in a single division or county, respectively.

Critical Crash Rate Method

A simple comparison of the roadway crash rate vs. the average crash rate would flag approximately one-half of all locations as having a potential highway safety concern. A more appropriate method is the *critical crash rate method*. This statistical tool can be used to screen for high accident locations, by utilizing a *confidence interval* that can be adjusted up or down to accommodate the needs of your safety program. If a segment has an actual crash rate higher than the critical rate, the location may have a potential highway safety deficiency and may deem additional analysis. The additional analyses may include but are not limited to the following: *crash pattern studies, severity studies, B/C ratio studies, engineering investigation, etc*. To compute the critical crash rate for a site, use the following equation:

$$F_c = F_a + k(F_a / M)^{1/2} + 1/2M$$

where:

- F_c = the critical crash rate
- F_a = statewide crash rate of roadway class or average crash rate
- K = a probability constant. For example:
  - K = 1.645 for a 95% confidence level
  - K = 2.576 for a 99.5% confidence level
- M = vehicle exposure (see paragraph below)

The exposure, *M*, can be expressed in million entering vehicles (*mev*) for intersections or million vehicle-miles (mvm) for sections. The critical crash rate formula is a “unit less” equation. It is not necessary to change the coefficients with other measuring units as long as you use matching units for average crash rate and exposure. The exposure should be calculated in *100mvmt* if *NC* S*tatewide Rates* is used. A historical perspective of the critical rate formula was provided by Stokes and Mutabazi (1).

NCDOT typically uses a 95% confidence level. Other probability constants do exist and may be relevant in some situations.

Another advantage of using the critical crash rate method is because it accounts for exposure. A short segment of roadway could have an extremely high crash rate although the roadway’s crash history identified only a small number of crashes. Locations with low exposure will be measured against a higher critical rate. Thus, the locations that have a small segment length (or low ADT) and low crash counts will not be overflagged when compared to locations that have high ADT’s and high crash counts.

Example

Calculate the F_c, the critical crash rate, for the roadway section discussed earlier. A 3-year crash history was completed for the 0.92-mile section of US 301 in Smithfield and the completed study included 145 total reported crashes (See Exhibit 3). The ADT for this segment was 24,000 vpd and the vehicle exposure is calculated to be 24.2 *mvmt* or (0.242 *100mvmt)*. The calculated total crash rate is 599.18 *crashes per 100mvmt.* According to the *2000 -2002 NC Statewide Rates,* the statewide crash rate for United States routes with a continuous left-turn lane is *374.08 crashes per 100 mvmt.* This will be used for the average crash rate, F_a. This calculation will use $k = 1.645$ which is the value used for the 95 % confidence level.

$$F_c = 374.08 + 1.645 * (374.08/0.242)^{1/2} + 1/(2*0.242) = 440.83\ crashes\ \ per\ 100mvmt$$

Therefore, the crash rate for this segment is higher than the critical crash rate, 599.18 > 440.83 *crashes per 100mvmt*.

North Carolina Department of Transportation
Traffic Engineering Accident Analysis System
Strip Analysis Report

Summary Statistics

High Level Crash Summary

Crash Type	Number of Crashes	Percent of Total
Total Crashes	145	100.00
Fatal Crashes	0	0.00
Non-Fatal Injury Crashes	48	33.10
Total Injury Crashes	48	33.10
Property Damage Only Crashes	97	66.90
Night Crashes	15	10.34
Wet Crashes	23	15.86
Alcohol/Drugs Involvement Crashes	1	0.69

Vehicle Exposure Statistics

Annual ADT = 24000

Total Length = 0.92 (Miles) **1.481 (Kilometers)**

Total Vehicle Exposure = 24.2 (MVMT) **38.95 (MVKMT)**

Crash Rate	Crashes Per 100 Million Vehicle Miles	Crashes Per 100 Million Vehicle Kilometers
Total Crash Rate	599.18	372.27
Fatal Crash Rate	0.00	0.00
Non Fatal Crash Rate	198.35	123.23
Night Crash Rate	61.98	38.51
Wet Crash Rate	95.04	59.05
EPDO Rate	2914.92	1811.04

Exhibit 3 – 2000 – 2002 Crash Rates for Example Section

Metric Conversion

The ***NC* S*tatewide Rates*** calculated crash rates in units of *crashes per 100 million vehicle miles traveled.* To convert to metric units or *crashes per 100 million vehicle kilometers traveled* divide the crash rates by *1.609.* For example:

$$374.08\ crashes\ \ per\ 100mvmt \div 1.609 = 232.49\ crashes\ \ per\ 100mvkt$$

CRASH SEVERITY

A roadway location that has a history of fatal and severe injuries warrants more attention than a location that has a history of minor "fender benders". The *Severity Index* is a popular tool used to identify locations that have a high percentage of severe crashes.

The EPDO Index is a method of weighing the costs of fatal and injury crashes in terms of a property damage only crash. According to NCDOT practice and policy, a K or A injury crash is calculated to be 76.8 times more costly than a PDO crash and a B or C injury crash is calculated to be 8.4 times the cost of a PDO crash.

EPDO Index = 76.8(K+A) + 8.4(B+C) +PDO where

K = the number of fatal crashes
A = the number of A injury crashes
B = the number of B injury crashes
C = the number of C injury crashes
PDO = the number of PDO crashes

EPDO Rate = EPDO Index / exposure

Severity Index = EPDO Index / number of crashes

This number measures the weighted cost calculated by the EPDO Index in terms of total number of crashes at a location. This statistic is beneficial in identifying locations with a disproportionately high number of severe type crashes

Highway Safety Improvement Program

The purpose of the North Carolina Highway Safety Improvement Program (HSIP) is to provide a continuous and systematic procedure that identifies and reviews specific traffic safety issues in the state and to determine potentially hazardous (PH) locations that are possibly deficient in these issues. The Traffic Safety Unit (TSU) staff continuously strives to improve the identification of relevant traffic safety issues, minimum warranting criteria, and the location selection process.

Reference

1. Stokes, R.W., and M.I. Mutabazi. Rate-Quality Control Method of Identifying Hazardous Road Locations. In *Transportation Research Record 1542,* TRB, National Research Council, Washington, D.C., 1996, pp. 44-48.

<u>Examples of Road Types</u>

Exhibit 3 - 2 Lanes Undivided

Exhibit 4 – 2 Lanes Cont. Left Turn Lane

Exhibit 5 – 3 Lanes Undivided

Exhibit 6 – 4 or More Lanes Undivided

Exhibit 7 – 4 or More Lanes Cont. Left Turn Lane

Exhibit 8 – 4 or More Lanes Divided

Rate-Quality Control Method of Identifying Hazardous Road Locations

ROBERT W. STOKES AND MADANIYO I. MUTABAZI

A brief historical perspective on the development of the rate-quality control method and its use in the identification of hazardous roadway locations is presented. The evolution of the formulas used in the rate-quality control method from their origin in the late 1950s to their present form is traced. The derivation of the basic formulas used in the method is also presented and discussed. It is suggested that, contrary to assertions in the literature, the accuracy of the equations used in the rate-quality method is not improved by eliminating the normal approximation correction factor from the original equations. The need for the correction factor is particularly apparent at higher probability levels. Charts are provided for determining an appropriate correction factor for those who may wish to incorporate these factors into the equations.

The rate-quality control method is used by many transportation agencies to identify hazardous road locations. This method uses a statistical test to determine whether the traffic accident rate for a particular intersection or roadway segment is abnormally high when compared with the rate for other locations with similar characteristics. The statistical test is based on the assumptions that traffic crashes are rare events and that the probability of their occurrence can be approximated by the Poisson distribution (*1*). The critical accident rate is determined statistically as a function of the systemwide average accident rate for the category of highway and the vehicle exposure (vehicles or vehicle kilometers) at the location being studied. If the actual (observed) accident rate for a particular roadway location is equal to or greater than the critical rate, the deviation is probably not due to chance and may be considered to be significantly greater than average. The formula often used to establish the critical accident rate at or above which a roadway location is considered hazardous is (*1*)

$$R_c = \lambda + k\sqrt{\frac{\lambda}{m}} + \frac{1}{2m} \tag{1}$$

where

R_c = critical rate for particular location (accidents per million vehicles or accidents per million vehicle-km),
λ = average accident rate for all road locations of like characteristics (accidents per million vehicles or million vehicle-km),
m = number of vehicles traversing particular road section (millions of vehicle-km) or number of vehicles entering particular intersection (millions of vehicles) during the analysis period, and
k = probability factor determined by the level of statistical significance desired for R_c.

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This paper provides a brief historical perspective on the development of the rate-quality control method and its use in the identification of hazardous roadway locations. The paper traces the evolution of the formulas used in the rate-quality control method from their origin in the late 1950s to their present form. The derivation of the basic formulas used in the method is also presented and discussed.

HISTORICAL PERSPECTIVE

Statistical quality control techniques were originally developed as a means to dynamically control the quality of industrial production. By setting upper and lower control limits on the amount of variability permitted in a particular process and by periodically sampling product quality, these techniques can provide a means of verifying that a process is in control. The control limits and the results of the periodic samples of product quality can be plotted on a control chart and any sample measures of product quality that fall outside the critical values established by the control limits are said to be out of control. The greater the difference between the observed sample values and the critical control limits, the less likely that the out-of-control situation is caused by chance and the more likely that the process needs correction of some kind.

In 1956, a method was proposed to analyze accident data for highway sections based on statistical quality control techniques (*2*). A procedure was described for determining the amount of variability in the accident rate that could be expected as a result of chance for any highway control section. By applying the following equations, the upper and lower control limits on the overall accident rate are established for each control section.

$$\mathrm{UCL} = \lambda + 2.576\sqrt{\frac{\lambda}{m}} + \frac{0.829}{m} + \frac{1}{2m} \tag{2}$$

$$\mathrm{LCL} = \lambda - 2.576\sqrt{\frac{\lambda}{m}} + \frac{0.829}{m} - \frac{1}{2m} \tag{3}$$

where

UCL = upper control limit,
λ = average accident rate for all road sections of like characteristics (accidents per 10 million vehicles-mi),
m = number of vehicles traversing road section during analysis period (10 millions of vehicle-mi), and
LCL = lower control limit.

In Equations 2 and 3, the first two terms result from the normal approximation to the Poisson distribution, the third term is a correction to the normal approximation, and the last term is a correction factor necessary because only integer values are possible for the observed number of accidents [i.e., a correction for continuity necessary when using the normal distribution to approximate a discrete distribution (*3*, pp. 84–85)]. The coefficient of the second term (2.576) is based on a probability level of 0.995 for each control limit.

The third term in Equations 2 and 3 is particularly interesting. The normality correction factor in Equations 2 and 3 is a function of the desired probability level and an assumed mean accident frequency. As discussed subsequently, this factor appears to have been the subject of some confusion in later efforts to refine the original equations proposed by Norden et al. (*2*). It appears that some early researchers may have viewed Equations 2 and 3 as generic formulas, when in fact they were based on a specific probability level and accident frequency.

The underlying statistical theory for Equations 2 and 3 is presented in a subsequent section of this paper. That presentation is preceded by a continuation of the discussion about the evolution of the formulas originally developed by Norden et al.

In 1962 and 1967, modified forms (*4*,*5*) of the formulas developed by Norden et al. (*2*) in the analysis of highway crash data were applied. The effects of different probability levels were tested (*4*) by varying the *k*-values in Equations 2 and 3. However, the normality correction factors in Equations 2 and 3 were not adjusted to reflect the new *k*-values (*4*).

In 1967, it was suggested (*5*) that the "validity of the equations is improved if the correction term (0.829/*m*) as it appears in the original equations (Equations 2 and 3) is omitted." Equations 4 and 5 reflect proposed revisions (*5*) to the original equations.

$$\text{UCL} = \lambda + k\sqrt{\frac{\lambda}{m}} + \frac{1}{2m} \tag{4}$$

$$\text{LCL} = \lambda - k\sqrt{\frac{\lambda}{m}} - \frac{1}{2m} \tag{5}$$

The recommendation (*5*) to eliminate the correction factor in the original equations was based on a comparison of the errors in the expected number of accidents (λm) as estimated from Equations 2 and 4. The comparison was for cases where the average number of accidents varied from about 0.3 to 13 accidents for the 90 and 95 percent probability levels (see Table 1). A more equitable comparison would have been to compare the estimation errors from Equations 2 and 4 at the probability level used to determine the original correction factor (i.e., the 99.5 percent level). Alternatively, new correction factors could have been calculated based on the 90 and 95 percent probability levels and the accident frequencies used in the comparison (*5*). These points will be discussed further later in this paper.

Equations 4 and 5 represent the formulas most widely used to establish the upper and lower control limits for the rate-quality control method. Equations 4 and 5 are cited in descriptions of the rate-quality control method (*1*,*6*,*7*). FHWA (*8*), however, provides the following equation for calculating critical accident rates:

$$R_c = \lambda + k\sqrt{\frac{\lambda}{m}} - \frac{1}{2m} \tag{6}$$

Note that Equations 4 and 6 are identical except for the sign of the last term. Equations 4 and 6 illustrate a subtle difference in interpretation that results when the continuity correction factor is added to rather than subtracted from the equation. Equation 4 provides an expression for the upper control limit that has a probability $1 - P$ of being equaled or exceeded by chance, where P = a given probability level. Equation 6 provides an expression for the upper control limit that has a probability $1 - P$ of being exceeded by chance.

TABLE 1 Comparison of Equations 2 and 4 (*5*)

Probability Level	Accident Frequency	% Error in Eq. 2	% Error in Eq. 4
0.95	0.325	33	-8.5
0.95	1.970	12	-4.6
0.95	11.638	3	-1.4
0.90	0.530	40	-1.8
0.90	1.103	26	-1.7
0.90	12.820	4	-0.5

ANOTHER LOOK AT RATE-QUALITY CONTROL METHOD

The following sections present a derivation of the basic equations used to establish the control limits on accident rates. The derivation provides a useful format to discuss the underlying statistical theory and to elaborate on several points of controversy alluded to earlier. The derivation closely parallels the approach taken by Norden et al. (*2*) in 1956.

Derivation of Control Limit Formulas

The occurrence or nonoccurrence of highway accidents may be modeled by a Bernoulli sequence, which, when stated in terms of the present problem, is based on the following assumptions: (a) each trial (vehicle-km) has only two possible outcomes (i.e., the occurrence or nonoccurrence of an accident), (b) the probability of occurrence of an accident in each veh-km is constant, and (c) the trials (veh-km) are statistically independent. If the probability of occurrence of an accident in each veh-km is λ (and the probability of nonoccurrence is $1 - \lambda$), then the probability of exactly *x* accidents in *m* veh-km in a Bernoulli sequence is given by the binomial probability mass function (PMF) as follows (*9*):

$$p(x) = \frac{m!}{x!(m-x)!}\lambda^x(1-\lambda)^{m-x} \tag{7}$$

Equation 7, although appealing in its simplicity, is readily applicable only for integer values of *m* (veh-km). However, when λ is small and *m* is large such that λm remains fixed, it can be shown that a good approximation to $p(x)$ can be obtained from Equation 8 (*10*):

$$p(x) = \frac{e^{-\lambda m}(\lambda m)^x}{x!} \tag{8}$$

where *e* is the base of the natural logarithms. Equation 8 is, of course, the familiar Poisson PMF. If the product λm (the expected number of accidents in *m* veh-km) is replaced with F_a, Equation 8 can be rewritten as

$$p(x) = \frac{e^{-F_a} F_a^x}{x!} \tag{8a}$$

Equation 8a describes the frequency of accidents as a Poisson process with mean and variance F_a. The corresponding process for accident rates (R_a) is also Poisson with mean and variance F_a/m.

Equation 8a can be used to formulate upper and lower control limits (confidence intervals) in terms of accident frequencies or accident rates. Because of the inherent intractability of evaluating the *x/m* factorial for the accident rate process, it is convenient to initially formulate the control limits in terms of accident frequency. The resulting control limits can then be converted to reflect accident rates by simply dividing by *m*. The basic approach is illustrated in the following summary of the procedure used by Norden et al. (*2*) to estimate Equations 2 and 3.

A table of the Poisson distribution was used (*2*) to obtain an upper and lower limit, *U* and *L*, on F_a (the expected number of accidents), such that $p(X \geq U) = 0.005$ and $p(X \leq L) = 0.005$, where *X* is the observed number of accidents along the test sections of a particular highway [the name or length of the highway is not specified (*2*)]. The resulting upper and lower limits on number of accidents were divided by *m* (veh-mi) to obtain the corresponding limits for the observed accident rate. Control charts showing the observed accident rate, the upper and lower control limits on accident rates, and the central value (assumed accident rate) were then plotted for each of the 18 highway intervals considered.

The formulation of control limits from a table of the Poisson distribution requires a double interpolation (for F_a and for *x*) for each road interval. It was reported (*2*) that the normal approximation to the Poisson provided an excellent approximation to the control limits without the need for tedious interpolations from the table of the Poisson distribution.

If the mean and variance of the Poisson distribution to be approximated are used to specify the mean and variance of the approximating normal distribution, then the general form of the equation for the confidence interval for F_a is

$$\left.\begin{matrix} U \\ L \end{matrix}\right\} = F_a \pm Z\sqrt{F_a} \tag{9}$$

where *Z* is the standard normal variate corresponding to the required confidence level.

All that remains to complete the derivation of the general formulas suggested (*2*) for computing the upper and lower limits on accident frequency is to insert the appropriate *Z*-score (2.576 for a 99.5 percent probability level for each limit), the normal approximation correction factor (0.829), and the continuity correction factor (½) into Equation 9. Incorporating these additional factors into Equation 9 and dividing by *m* (veh-mi) lead to the formulas for the upper and lower control limits on the overall accident rate given by Equations 2 and 3.

The need for the continuity correction factor in Equations 2 and 3 is well documented elsewhere (*3*, pp. 84–85) and is not recounted in this paper. The basis for the normal approximation correction factor in Equations 2 and 3, however, warrants additional discussion.

Normal Approximation Correction Factor

The normal approximation correction factor proposed (*2*) is examined in this section. The discussion focuses on the calculation of the correction factors and their effects on the accuracy of the equations. The discussion is limited to the correction factors for the upper control limits on accident frequency.

The normal approximation correction factor is simply the difference between the true and approximate (estimated) upper limits on accident frequency, as computed from Equations 10 and 11, respectively.

$$p = \sum_{x=0}^{U-1} \frac{e^{-F_a} F_a^x}{x!} \tag{10}$$

$$U_e = F_a + Z\sqrt{F_a} + 0.5 \tag{11}$$

where

p = prescribed probability level,
U = true upper control limit on accident frequency, and
U_e = estimated upper control limit on accident frequency.

Figures 1 through 3 show the normal approximation correction factors ($U - U_e$) for a range of frequencies from 0 to 30 accidents for standard probability levels of 0.90, 0.95, and 0.995, respectively. The correction factors in Figures 1 through 3 were calculated by selecting values for F_a that correspond to the specified probability levels. This approach was used (*5*) in constructing Table 1. [The authors' calculations indicate that the first entry in the second column of Table 1 should be 0.352 instead of 0.325, as reported by Morin (*5*).]

Note in Figures 1 through 3 that the curves flatten noticeably for frequencies in the range of about five or more accidents. For the 90 and 95 percent probability levels the correction factors are relatively small and probably have little practical significance in terms of improving the accuracy of the equations. The correction factors for the 99.5 percent probability level (Figure 3), however, are of sufficient magnitude to substantially affect the accuracy of the equations. Note also that for the 99.5 percent probability level the correction factors for frequencies greater than about five accidents are generally consistent with the value of 0.829 suggested elsewhere (*2*) in Equation 2.

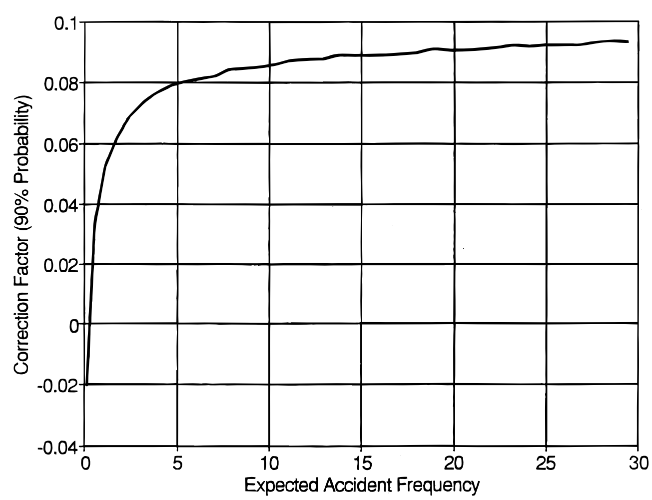

FIGURE 1 Normal approximation correction factors for upper control limit at 90 percent probability level.

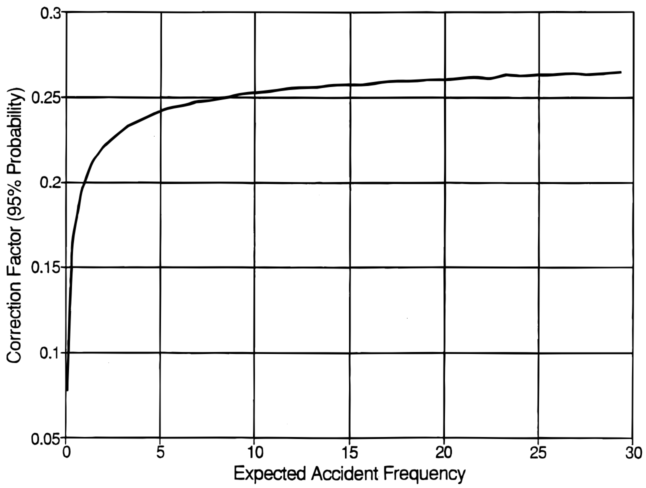

FIGURE 2 Normal approximation correction factors for upper control limit at 95 percent probability level.

Tables 2 through 4 present comparisons of the accuracy of the formulas for the upper control limits with and without the normal approximation correction factors. As shown in the tables, the incorporation of the appropriate correction factors results in consistently better estimates of the upper control limits on accident frequencies. However, as noted, the correction factors for the 90 and 95 percent probability levels are relatively small and for practical purposes could be omitted from the equations.

In a previous section of this paper it was noted that Morin (*5*) suggested that the "validity of the equations is improved if the 'correction term' (0.829/*m*) as appears in the original equations (Equations 2 and 3) is omitted." That recommendation (*5*) to eliminate the correction factor in the original equations was based on a comparison of the errors in the expected number of accidents as estimated from Equations 2 and 4. The comparison was for cases where the average number of accidents varied from about 0.3 to 13 accidents for the 90 and 95 percent probability levels (see Table 1). A more equitable comparison would have been to compare the estimation errors from Equations 2 and 4 at the probability level used to determine the original correction factor (i.e., the 99.5 percent level). Table 4 shows that comparison. Alternatively, new correction factors could have been calculated (*5*) based on the 90 and 95 percent probability levels and the accident frequencies used in the comparison. Tables 2 and 3 show the results of those comparisons. As shown in Tables 2 through 4, the accuracy of the control limits is improved if the appropriate normal approximation correction factors are included in the equations. The improvement is particularly noteworthy at the 99.5 percent probability level.

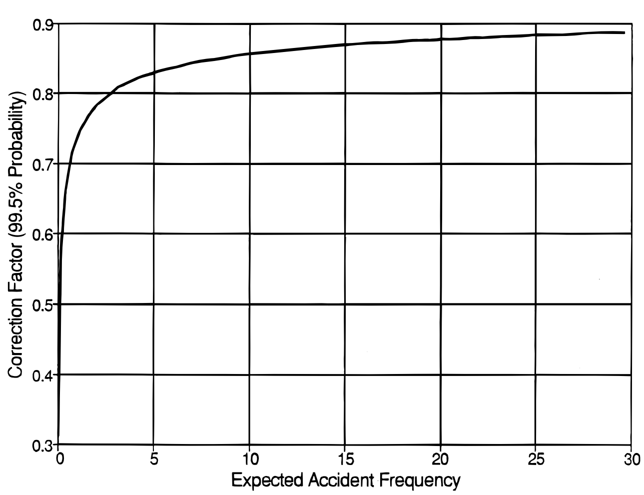

FIGURE 3 Normal approximation correction factors for upper control limit at 99.5 percent probability level.

TABLE 2 Accuracy of Formula for Upper Control Limit With and Without Normal Approximation Correction Factor for 90 Percent Probability Level

Accident Frequency	z-value	Percent Error	
		w/correction	w/o correction
0.105	1.282	0.64	2.04
0.532	1.282	-1.30	-1.65
1.102	1.282	-0.57	-1.74
2.432	1.282	-0.23	-1.37
11.135	1.282	-0.02	-0.54
12.822	1.282	-0.01	-0.45

Note: Correction factors are from Figure 1.

TABLE 3 Accuracy of Formula for Upper Control Limit With and Without Normal Approximation Correction Factor for 95 percent Probability Level

Accident Frequency	z-value	Percent Error	
		w/correction	w/o correction
0.355	1.645	-0.09	-8.24
0.818	1.645	0.03	-6.47
1.366	1.645	0.02	-5.28
1.97	1.645	0.00	-4.42
11.634	1.645	0.00	-1.42
12.442	1.645	0.00	-1.35

Note: Correction factors are from Figure 2.

TABLE 4 Accuracy of Formula for Upper Control Limit With and Without Normal Approximation Correction Factor for 99.5 percent Probability Level

Accident Frequency	z-value	Percent Error	
		w/correction	w/o correction
0.338	2.576	-0.18	-22.15
0.672	2.576	-0.01	-17.91
1.537	2.576	0.01	-12.82
2.038	2.576	0.02	-11.21
11.792	2.576	0.00	-3.92
12.521	2.576	0.00	-3.76

Note: Correction factors are from Figure 3.

SUMMARY AND CONCLUSIONS

This paper provides a brief historical perspective on the development of the rate-quality control method and its use in the identification of hazardous roadway locations. The paper traces the evolution of the formulas used in the rate-quality control method from their origin in the late 1950s to their present form. The derivation of the basic formulas used in the method is also presented and discussed.

It is suggested that, contrary to assertions in the literature, the accuracy of the equations used in the rate-quality method is not improved by eliminating the normal approximation correction factor from the original equations (Equations 2 and 3). The need for the correction factor is particularly apparent at higher probability levels.

Equation 12 can be used by the analyst who wishes to consider the normal approximation correction factor when calculating the upper control limits on accident frequency.

$$\text{UCL} = F_a + Z\sqrt{F_a} + c + 0.5 \qquad (12)$$

where c is the normal approximation correction factor. The appropriate c-value can be determined from Figure 1, 2, or 3.

Similarly, Equations 2 and 3 can be generalized to reflect the upper and lower control limits for accident rates at the desired probability level by replacing the coefficients of the second terms (2.576) and the numerators of the third terms (0.829) with the appropriate Z- and c-values, respectively.

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Publication of this paper sponsored by Committee on Statistical Methodology and Statistical Computer Software in Transportation Research.